Synthetic Modelling of Pedestrian Movement

Tallinn case study report

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This paper builds towards the argument that pedestrian traffic in the city can be successfully simulated with agent-based computational models if pedestrians' movement patterns are appropriately studied first. Furthermore, such simulation models, when finely calibrated and supported by onsite observations, allow planners to evaluate different urban design scenarios. We present a pilot study carried out in the centre of Tallinn, and discuss a way of how pedestrian movement simulations can be conceived. In the pilot study we recorded some 120 traces of pedestrians' movement and developed a prototype of an agent-based computational model to simulate this movement. Additionally we investigated the possibility of including solar analysis into the computational model. Already this short exercise offered us some interesting insights into how certain spatial qualities and features can drive pedestrian traffic making urban walkers to verge off the shortest routes. The pilot study was carried out in the context of the High Street project [1] for turning the centre of Tallinn into more pedestrian friendly area by redesigning urban space, calming vehicular traffic and creating new opportunities for businesses to flourish.

Keywords: agent-based model, urban analysis, pedestrian simulation, movement patterns, solar analysis

BACKGROUND

Agent-based models have been used in urban and spatial analysis before. Perhaps the best known is the Space Syntax approach. For example, Penn and Turner (2003) demonstrate that space layout in urban settings affects search efficiency of agents. Space Syntax tends to use pre-calculated visibility graphs and their agents possess no knowledge of urban space nor have they particular targets. They are sort
of random walkers (Batty 2003) purely reacting to the degree of visibility in open space. However, this behaviour is probably not a standard case in any city. At least in our short pilot study in the centre of Tallinn we observed only a few occasions when people did not seem to have a particular destination and were simply guided by ad-hoc decisions. Following this observation, our simulation model is opposed to the agent-based model used in Space Syntax studies and to the mere modelling origins and destinations. Instead, we assume that simulation agents "know" the shortest path between their origin and their destination. Nevertheless, an agent may not always choose the shortest route since its navigational decisions are also affected by some local spatial features pertaining to the configuration of space and urban morphology. Such features are associated but not limited to wider pavements, less noise, sunnier or greener space, and the activities certain streets or spaces offer.

Some models, most notably in Space Syntax, try to simulate pedestrian movement purely based on physical configuration of space and urban layout (Penn and Turner 2002, Penn and Turner 2003). The speciality of our approach is to acknowledge that pedestrians, due to socio-cultural background, move differently from country to country and from city to city. Thus, we first observe behaviour of pedestrians on the site and then adjust our simulation model based on these observations.

Our method is relatively new in the Nordic region of Europe but it has developed upon well-known academic theories and approaches shared all over the world. The analytics methods that we are going to deploy for the Tallinn High Street larger scale study are pretty solid and developed on the field as they were recently used in commissioned project by SPIN Unit together with the Estonian Academy of Arts for the City of Turku (Cerrone et al. 2005) and for Urban Design London with Transport For London. In the first case we developed a study and a plan for revitalisation of the city centre and transportation planning. In the case of London, we have focused on the area of King's Cross, using social media data to analyse spatio-temporal patterns and assess the impact of new development on retail clusters present in the area. Working for Turku and London, gave us experience and confidence on our method and has consolidated our practice.

Cities are places of opportunity and innovation and generate new emotions and spontaneous activities. The complexity of human activities and exchange is what gives urban spaces particular dynamics, making some streets more successful than others. Attempts to model the key factors of pedestrian movement can be found in the form of multiple scientific approaches and analytic methods developed in the fields of urban studies (e.g. Batty 2003), spatial cognition (e.g. Tahrani et al. 2005) and travelling behaviour studies (e.g. Broach et al. 2009). So far, there is not one theory or one model that can unify the description of pedestrians' path choice into one assumption due to the complexity of spatial dynamics and behavioural patterns. In order to tackle the complexity and dynamism of social and architectural urban features, it may be possible to assemble models describing the complexity of the relations and collisions between individuals and the city or simplify the problem by reducing the amount of generalisations and assumption by carrying out actual observations in a limited and relatively small urban area. We chose to focus on observations based modelling because our interest as scholars is to bring people back to the centre of our studies, where human behaviour is no longer attempted to be generalised and described by a model it characterise them.

We assume that good urban form, good accessibility, social activities and commercial services located along streets are all needed in order to create a space for everyone. Streets generate movement and attract people thanks to both their physical configuration and the activities they afford and accommodate. Public space should promote integration of people of different classes, ages and social hierarchies. Higher levels of inclusion leads to a higher number of people walking on the streets and using the services offered.
In order to provide new tangible spaces and propose innovative improvement of the existing ones we start by mapping and analysing pedestrians movement, that is one of the main resources of small urban cores or historic towns. We study the area near Viru Väljak in Tallinn because it is the meeting point of the historic town with the new urban core. It allows us to address the need of fostering pedestrian movement in the historic town to improve tourism and accessibility. The new urban core, which is mainly designed for cars, demands to be redesigned to foster pedestrian movement and permeability between the functionalistic architecture that characterises it - better planning of pedestrian movement is necessary to the survival of both.

THE PILOT STUDY

Our pilot study demonstrates how principles of synthetic modelling (Morse et al. 2008) can be used to simulate pedestrian traffic within an urban area. Synthetic modelling method allows development and fine-tuning of computational simulation models based on real-world data. In a nutshell, synthetic modelling is an iterative method of developing computational systems that simulate real-world phenomena by the means of observation, modelling and comparison. A synthetic modeller is not as much concerned with the exactness of the model components as with making sure that the model produces similar patterns to those that are observed in reality. In our case of simulating pedestrian movement we modify and calibrate the model until walkers in the simulation model start choosing similar trails to those of real pedestrians.

The first step of our study is mapping pedestrians' traces to quantify and characterise movement in the area. We organised an intensive workshop with masters students at the Architecture department of the Estonian Academy of Arts to trace and record pedestrian' paths in the area of Viru Väljak using GPS enabled smartphones. A group of 10-12 students recorded over one hundred pedestrians' tracks from their origin to their destination within the area of interest, during a 2-hour study. These tracks were later mapped to a GIS application. Then a series of agent-based simulation models were devised to mimic particular behavioural properties of pedestrian movement that we observed. Once selected algorithms were compiled into a single model, several iterations of simulation model development and comparison of simulation results with the recorded GPS tracks was carried out. The simulation model was thereafter modified and compared to the real world data until the tracks left behind by agents bore strong enough resemblance to the GPS tracks. If at first this appears as an exercise of remodelling natural movement, our approach can be used to simulate and study the impact of proposed urban transformation in the scale of 10 city blocks.

Common methods deployed to study pedestrian movements use surveyors standing at certain gates and counting people passing the gates. Gates (see Figure 2) are imaginary access and exit points, perpendicular to a street and for this reasons they can only measure how many people move in or out a certain street. Another approach is counting pedestrians arriving to origin points or destinations. In our study we combine both approaches to characterise pedestrian movement with surveyors following pedestrians from one gate to the next one. We divided surveyors into two groups: one group starts recording tracks from a set of selected origins (transportation nodes) till their destinations (transporta-
tion nodes, retails, building etc.) or till they cross one edge (gate) of the area of interest; the second group starts recording tracks from a given edge (gate) of the area of interest till another edge or till the path ends into a destination.

What makes this method valuable to characterise pedestrian movement is that once data is loaded and mapped into GIS we can see what are the major attractors within our area of interest - we can map the path density to highlight the street segments where pedestrians are more likely to be passing by and we can observe behaviour patterns in regards to path choice. Also, we can analyse individual pedestrian journeys (see Figure 3) one by one. This information will be later used to warp the computer simulation in order to set attractors and flow density based on these observations.

The field observations help us to identify features that attract pedestrian traffic - magnets, as we call them. These magnets make walking easier, more pleasurable or more purposeful. Magnets can be spatial (e.g. width of pavement), functional (cafes, shops) or environmental e.g. noise, sunniness, general thermal comfort (Mayer et al. 2008).

Despite the field work carried out in the pilot study was extremely insightful for understanding pedestrian movement, it was also very labour intensive. This type of studies should be carried out regularly and in much larger scale. Only then we can hope of building and calibrating a truly validated simulation model.

There were a few ways that we can consider extending the pedestrian traffic data collection methods.

1. One of the possible ways is to use active mobile positioning method as described by Tiru

Figure 3
Pedestrian tracks recorded by students in outdoor studies.
(2011) - a method where "location request can be initiated from the mobile device itself (by its user) or from outside." In the latter case, the consent of the owner of the device is needed. This means that for active positioning, we need to get people to install a mobile application (e.g. OSMTracker) and send us the data that they have collected, or we can develop our own application that facilitates automatic collection of GPS data from devices.

2. We can use pedestrian detection cameras and convert movement paths to GPS tracks. A variety of methods have been developed for tracking single or multiple pedestrians in static or moving cameras by exploiting different types of image information [2] Installing a camera-based tracking system requires a network of cameras to cover the entire study area.

3. Use a purpose made network of WiFi access points to detect all WiFi enabled devices.

4. We can use a purpose made sensory network in combination with low-cost tags or beacons that are given to the pedestrians at the gates. Potential options are a) Bluetooth Low Energy (BLE) beacons and b) RFID tags.

INTEGRATING STUDIES OF NATURAL LIGHT
The research already done in 1970's by William H. Whyte (1980) has shown that solar access and exposure are key factors in creating attractive settings for pedestrian gathering in streets and plazas. Thus one can assume that solar exposure level also affects the pedestrian choice of routes. Perhaps with a few exceptions of mid-summer’s extreme weather conditions in Tallinn and other cities in similar climatic zone, exposure to sunlight usually makes streets more attractive for walking. Therefore, direct exposure to sun can be considered as a magnet in the proposed simulation model. A study of how solar exposure impacts spatial perception in urban context has been connected to space acknowledgement in relation to analysis and effects within Virtual Reality (VR) environments (Tahrani et al. 2005). In our case the simulation of attraction to solar exposure is performed in 2D environment with a focus on pedestrian movement.

Unlike many other magnets pertaining the physical configuration of urban space such as the width of the pavements, transparency of the facades, ground surface materials etc., solar access is dynamically changing throughout the day. When using it as an input to the simulation model, one has to consider the temporal parameters of the model. E.g. if pedestrian movement is simulated during the morning rush hour then the solar analysis needs to be carried out within the same hours of the day. However, simulation can also be carried out within a specific timeframe (e.g. one day, week, month).

Our tests of solar exposure calculations were carried out by using the built-in analysis tools of Bentley Microstation. This particular package was chosen because of its broad handling of various geometry formats from different sources and the possibility of live links to WMS mapping data from Estonian Land Board (ELB), and general support for geolocated input data. Also according to our previous experience with other popular analysis packages, the geometry needed less repairing and re-meshing to become usable.

In order to carry out the study, a GIS database with 3D building models (copyright: Tallinna Linnaplaneerimise Amet) was translated to DWG format from ArcGIS by the Tallinn City Planning Office’s Geoinformatics and Cartography Department (Tallinna Linnaplaneerimise Amet, Geoinfomaatika ja kartograafia osakond). To further refine the location based solar exposure in terms of diffused light calculations, a general weather file for Estonia (so called Base Year data) was converted from Excel spreadsheet to Energy + .EPW format, usable by several climate analysis software packages in addition to Microstation’s built-in tools described above. To make a streamlined workflow between different software packages possible, i.e. easily machine-readable
data for pedestrian simulation, the results were customised by grey-scale values for hourly solar coverage, combined with an overlay of building data without the solar analysis in RGB 255 0 0 - leaving only the street level computations visible, and output as a 1:1000 scaled PNG raster image.

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The analysis results clearly demonstrated that the well exposed street sides in the pilot study area coincided with preferred routes of pedestrians, as well as shadowed spaces with more neglected areas in the urban environment in general. Although the pilot study area is fairly small, there is little doubt that we will be able to demonstrate the same correlation between sunny areas and preferred pedestrian routes with larger scale studies.

A further refinement considering the facade materials affecting street level glare and other factors affecting pedestrians, although of significance (Hagita and Mori 2013) has been decidedly left outside the scope of this study.

THE SIMULATION MODEL

The software prototype for simulating the pedestrian movement patterns is based on some earlier agent-based models done by Puusepp (2011). For the pilot study the model is developed in Netlogo that is well suited for testing early concepts and for building rapid prototypes. Netlogo works reasonably well for the size of the pilot study. For the larger scale project we anticipate some scalability issues, but this remains yet to be discovered.

While agent-based models have been heavily used in crowd modelling (Procházk et al. 2015) and evacuation (Helbing et al. 2002), there have been only a few examples of using agent-based models for studying pedestrian movement in urban spaces. One of the most notable is perhaps the STREET model (Haklay et al. 2001) that focuses on the simulation of the behavioural aspects of pedestrian movement in non-congested situations. The STREET model demonstrates that agent-based simulations are preferred over traditional pedestrian simulation models such as using Euclidean distances or shortest paths through the network of gravity models due to their flexible and distributed nature. Traditionally, movement studies measure the outcome produced by the current combination of street configuration and attractor (offices, shops, cafes etc.) locations; such models are better suited to modelling general patterns of movement and not so well applicable to model the movement of individuals. According to the authors of the STREET model “some researchers argue that the main generator of pedestrian movement is the configuration of the street network itself, and that patterns of movement are largely determined by this configuration, rather than by the distribution of attractors within the network. This is an extreme view, which is difficult to sustain without recourse to ceteris paribus arguments."

Also, seldom are the cases where qualities of urban space is considered as part of the decision making of pedestrian route selection mechanism. In contrast to traditional transportation planning models, agents are directly embedded into the digital representation of the studied urban environment and their route selection mechanism operates on the locally available data. Such models work better at small spatial scales, where movement of individuals becomes the focus of the computation. Arguably, local spatial and environmental qualities have a major impact on the route selection decisions at this scale.

Simulated pedestrians in our model are positioned on one particular location (origin) and given a target (destination) in the beginning of the simulation. They are simple reactive agents that move closer to their assigned destination by hill climbing pre-calculated proximity values towards their destination, but are simultaneously attracted to so-called
magnets - urban qualities defined by the modeller of the simulation. Our agent has a notional body with three sensors - one in front and two symmetrically on sides at a specific angle from the front sensor. These sensors read both the proximity and the magnetic values from the environment.

Proximity values are calculated separately for each destination and are inversely proportional to the topological distance from the target destination, taking into account barriers such as buildings and roads (see Figure 4). The environment is made of a set of patches (pixels) with each patch containing a proximity value to each destination point. This value is propagated from patch to patch with the passed value lessened in every iteration so that a gradient field of proximity values is formed. The patches gain the proximity value only from their immediate neighbours, which means that passing on the values happens only locally. This type cellular automata mechanism has been modelled and described in detail by Adamatzky (2001). A similar method has also been used in Daedalus computer program for creating and solving mazes [3].

In addition to proximity values, agents are also attracted to certain magnets in their environment. This setup reflects on the study that most people do not choose the shortest paths in the city (Zhu and Levinson 2015). We assume that unlike public transportation users pedestrians are more likely to base their choice of route on local spatial features. Therefore, we propose a hypothesis that pedestrians are attracted to some apparent features such as the width of passages, attractive street frontages, existence of greenery, exposure to sun, shelter from noise and adverse weather conditions, as well as to some other less tractable magnets such as visual variety of urban morphology. Figure 5 shows how the magnetism attracts pedestrian traffic in the simulation model.

There are two different kinds of input data to be loaded into the simulation model before the agents are set loose. The first kind of input is concerned with origins and destinations. In addition to the above described computation of proximity values to each designated destination, we also need a origin-destination (OD) matrix that defines the frequency of trips between all pairs of origins and destinations.

While we can run the simulation in the qualitative mode without the OD matrix, it would only help us to understand the change in route selection of individual pedestrians, but not give us the desired data.
about the overall change of the pedestrian traffic numbers in the area. There are a number of ways to compute the OD matrix. One of the ways to be considered for the large scale study is based on the gravity model (Torrens and Alberti 2000). In the gravity model each origin and destination is given a mass - a number of pedestrians that depart from and arrive to this point. A simple OD matrix can be calculated taking into account the mass of each OD point and the Euclidean distances between points. Getting accurate data about such numbers alone is tremendous amount of work. Ideally we would rely on exact counting methods but in reality this would need to be based on a combination of less accurate methods such as functional mapping of city blocks, data collected from transportation systems (in Tallinn’s case the “green card” data can be used) and available financial data from enterprises in the area.

The second kind of data that can be fed into the simulation model represents magnetic values of spaces. These magnets or urban qualities are either observed on the site or computed. Magnets can be inserted into the simulation manually by “painting” the streetscape with positive (attractive street sections) or negative (unpleasant areas for walking, e.g. pedestrian tunnels) magnetic values. Alternatively, the solar exposure maps (see Figure 6) can be loaded automatically. In the latter case, brighter colours in the solar exposure images are directly translated into positive magnetic values.

**FURTHER WORK**

Initial calibration of the simulation model was carried out by comparing GPS tracks recorded (see Figure 7) during outdoor studies with the tracks generated within the simulation model (see Figure 8). The calibration of the simulation model was an iterative procedure where the strength and positioning of urban magnets were finely tuned until the tracks left behind by agents bore strong enough resemblance to the GPS tracks. In addition, we have established a mechanism of taking environmental factors such as sun exposure into account.
With our early pilot study we have demonstrated that it is possible to build an agent-based simulation model combining outdoor observations and computed qualities of urban space. We will take this approach further and use synthetic modelling methodology to build an agent-based simulation model that can be turned into a mechanism for future-proofing urban design decisions, predicting how different spatial and functional scenarios affect pedestrian traffic in the centre of Tallinn. In order to do so, we will carry out an extended outdoor study observing how people navigate the area in reality and simulate it via computational means. We will carry out qualitative and quantitative spatial analysis and test the hypothesis of how different spatial features encourage or discourage the route selection mechanism of pedestrians. Understanding spatial magnets allows us to turn the simulation model into a stimulation model - an active construction that help to solve issues involved in designing new complex systems (Resnick 1994).

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